A COMPARISON OF HIP JOINT KINETICS DURING THE BARBELL HIP THRUST, DEADLIFT AND BACK SQUAT

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The barbell hip thrust, deadlift and back squat are all exercises designed to strengthen the hip extensor muscles. The aim of this study was to directly compare hip joint kinetics in the lifting phase of the barbell hip thrust with those in the deadlift and back squat. Six resistance-trained men performed one set of three repetitions at 90% 1RM of each exercise. Kinematic (250 Hz) and kinetic data (1000 Hz) were used to calculate hip angle and moment throughout each lifting phase. Analysis of continuous data revealed that the hip extensor moment was significantly greater early in the lifting phase in the deadlift and later in the lifting phase in the hip thrust. All three exercises clearly facilitate the strengthening of the hip extensors, and careful consideration of the specific desired adaptation is recommended when selecting exercises for this purpose.

KEY WORDS: 1D analysis, hip extensors, inverse dynamics, joint moment, strength training

INTRODUCTION: The barbell hip thrust was designed to increase the strength of the hip extensor muscles (Contreras et al., 2011). It has been suggested that the hip thrust increases tension in the hip extensor musculature as the hip joint reaches full extension, when compared to traditional standing barbell strength exercises such as the back squat and deadlift. This is thought to be the case due to the relative antero-posterior orientation of the force vector to the body segments in the hip thrust, compared to the superior-inferior orientation of the force vector in traditional standing barbell strength exercises, and is known as the force vector theory (Contreras et al., 2011). The barbell hip thrust is a popular exercise for sprint acceleration training, since it is thought to load the hip extensors to a greater extent near full extension with a horizontal force application (Contreras et al., 2017).
To date, studies of joint kinetics of the hip thrust are limited to a description of the loading at the hip throughout a repetition, which showed a peak extensor moment early in the lifting phase (Bezodis et al., 2017). Whilst the joint kinetics of the back squat and deadlift have previously been quantified (Swinton et al., 2011; Southwell et al., 2016; Legg et al., 2017), direct comparisons with the hip thrust are confined to analysis of electromyography (Contreras et al 2015; Andersen et al., 2018). Therefore, the aim of this study was to directly compare hip joint kinetics in the barbell hip thrust lifting phase with those in the deadlift and back squat.

METHODS: Data Collection: Six resistance trained males (24.0 ± 3.9 years, 85.8 ± 10.4 kg, 1.82 ± 0.09 m, hip thrust 1RM = 180 ± 46 kg, deadlift 1RM = 174 ± 35 kg, back squat 1RM = 145 ± 36 kg) gave written informed consent to participate after institutional ethical approval. Participants were free from injury and regularly used the three lifts in their training routine.
Kinematic data were captured at 250 Hz with a 15 camera Vicon Vantage system. A marker set comprising 26 individual markers and four four-marker clusters were attached to each participant to facilitate the creation of an eight-segment model (bilateral feet, shanks and thighs, pelvis and thorax). Three markers were attached to the barbell to track its position and orientation. Synchronised kinetic data were captured using three Kistler 9287 force plates (1000 Hz). Two were located in standard in-ground dwellings, and were used to measure forces separately at each foot. The third was mounted to a custom-built rig, specifically for measurement of the hip thrust. It was raised above the ground and angled at 20° to the horizontal, to facilitate accurate measurement of external force between the thorax and bench. A 15 mm medium density foam mat was secured to the top of the raised force plate to reduce participant discomfort. The rig was positioned such that the participant could comfortably perform the hip thrust with their feet located near the centre of the in-ground plates. Participants performed a self-selected warm-up. Data collection comprised one set of three repetitions of each lift at 90% 1RM, with self-selected rest permitted between sets.

Data Processing: After labelling and gap-filling of marker trajectories (Nexus, v2.6, Vicon, Oxford Metrics, UK), data processing was performed using Visual 3D software (v6, C-Motion Inc, Germantown, USA). Raw marker coordinates and force traces were low-pass filtered (4th order Butterworth) with cut-off frequencies of 3 and 30 Hz, respectively. Data from the raised force plate were rotated and resolved into the global coordinate system. Each segment's local coordinate system (SCS) was defined using a static trial, with the x-axis pointing right, y-axis forward and z-axis upwards. Joint angular velocity was the rate of change of the distal relative to the proximal SCS, described by an XYZ Cardan sequence. Newton-Euler inverse dynamic procedures (Selbie et al., 2014) were used to calculate resultant joint moments resolved in the proximal SCS at the ankle, knee, hip and trunk, with the analysis focused solely on the hip joint, to address the aim of this study. Due to the sagittal plane nature of the movement, x-axis data only are reported, with extension defined as positive. Analysis was undertaken on the lifting (bar-raising) phase of each repetition. The start of the lifting phase was defined by the onset of hip extension (when hip extensor angular velocity increased and remained above zero). The end of the lifting phase was defined by the maximum vertical barbell displacement. Joint moment data were normalised to body mass, and averaged over two limbs, and along with hip angle data, time-normalised to 100% of the lifting phase using a cubic spline.
Group means and standard deviations of continuous hip angle and moment were calculated using each participant's mean data from all repetitions. A Shapiro-Wilk test confirmed that data were not normally distributed. Statistical nonparametric mapping (SnPM) (Nichols & Holmes, 2002) was used to statistically compare selected waveforms between each lift. Specifically, a one-way ANOVA with post hoc test was used (α=0.05). Where the scalar output statistic, SnPM{f}, exceeded the critical threshold (f*) differences between conditions were deemed significant. f* is the value above which differences are significant at the specified alpha level. It is calculated as the $100(1-\alpha)^{th}$ percentile of the permutation distribution of the maximal statistic (Nichols & Holmes, 2002). Post hoc testing was conducted using SnPM independent t-test to provide the scalar output statistic, SnPM{t}. Critical thresholds (t*) were adjusted using a Bonferroni procedure. All SnPM analyses were done using open-source spm1d code (v.04, www.smp1d.org) in Matlab (R2017a, The Mathworks Inc, Natick, USA).

RESULTS: The hip extended throughout the lifting phase in all three lifts (Figure 1). The duration of the lifting phase was 1.198 ± 0.212, 1.732 ± 0.314 and 1.746 ± 0.231 s for the hip thrust, deadlift and back squat, respectively. Range of motion was smallest in the hip thrust. The hip angle was significantly more extended in the hip thrust compared to both deadlift and back squat for the first 85% and 97% of the lifting phase, respectively.

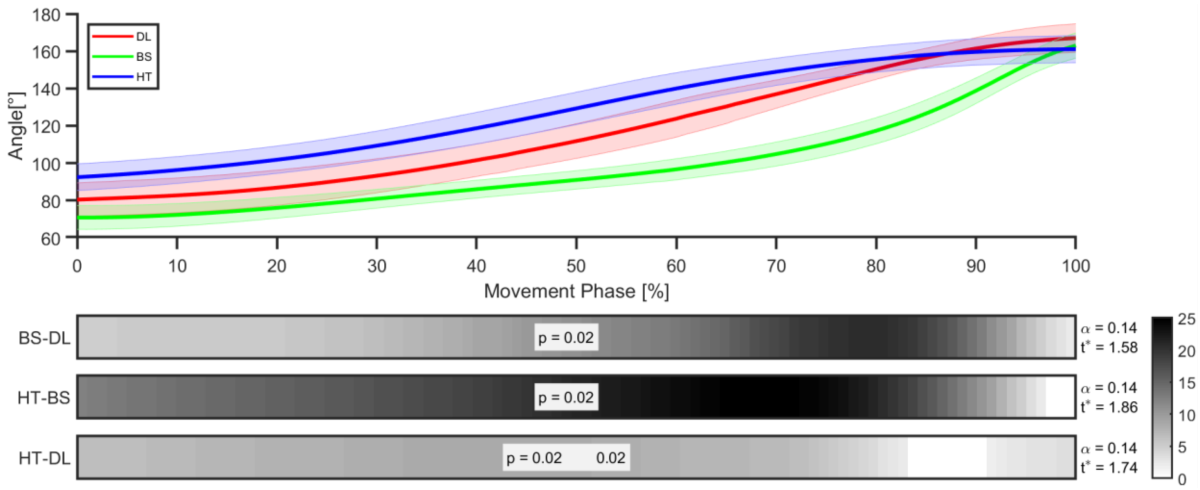

Figure 1: Mean ± standard deviation of hip angle throughout the lifting phase for hip thrust (HT, blue), deadlift (DL, red) and back squat (BS, green). Shaded bars represents the SnPM{t} output statistic for each comparison. Intensity of shaded areas indicate the extent to which the critical threshold (t*) was exceeded during the lifting phase.

In the early parts of the lifting phase, the hip extensor moment was significantly smaller in the back squat than the hip thrust and deadlift, from 3-35% and 0-56% of the phase respectively (Figure 2). In the middle of the lifting phase, there tended to be no significant difference in hip moment between the lifts. The largest significant differences in hip moment between lifts (darkest shading) occurred towards the end of the lifting phase, between the hip thrust and back squat (88-100%) and between the hip thrust and deadlift (80-100%).

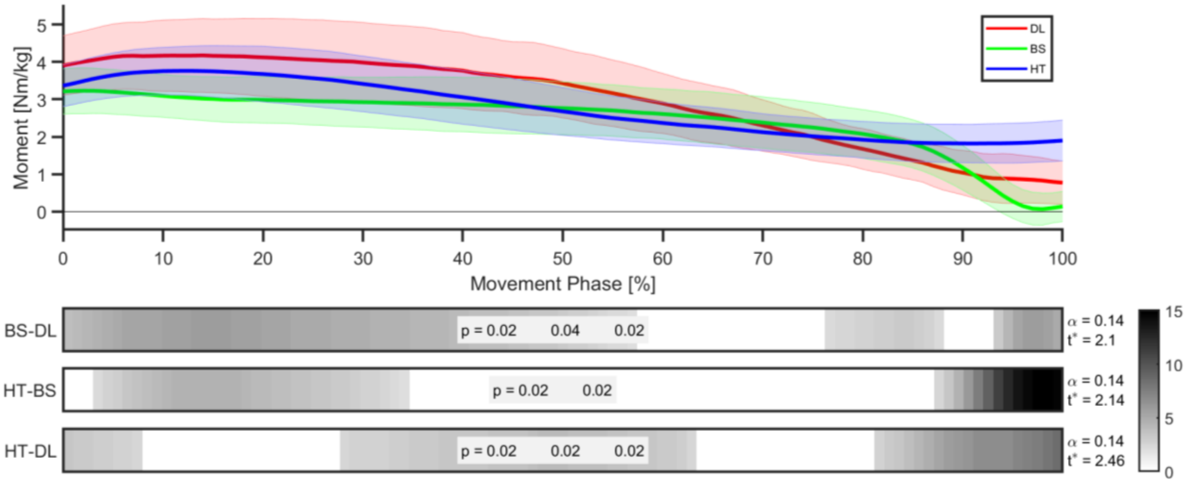

Figure 2: Mean ± standard deviation of hip moment throughout the lifting phase for hip thrust (HT, blue), deadlift (DL, red) and back squat (BS, green). Shaded bars represents the SnPM{t} output statistic for each comparison. Intensity of shaded areas indicate the extent to which the critical threshold (t*) was exceeded during the lifting phase.

DISCUSSION: The aim of this study was to directly compare hip joint kinetics in the lifting phase of the barbell hip thrust with those in the deadlift and back squat. To the authors' knowledge, this is the first study to successfully achieve that aim. It is clear that while there were a number of similarities between the lifts regarding the characteristics of the angle- and moment-time data, there were also some key differences, as shown by the SnPM analysis. The hip angle was more extended in the hip thrust throughout the majority of the lifting phase when compared to both deadlift and back squat. The back squat showed a relatively delayed hip extension action compared to the other two lifts.

Regarding the hip moment, the deadlift elicited a greater moment than the hip thrust, which in turn elicited a greater moment than the back squat at various stages throughout the first two thirds of the lifting phase. The back squat briefly caused a greater hip moment than the deadlift late in the lifting phase, before decreasing to near zero for the last 5% of the phase. The largest and most meaningful differences in hip moment occurred in the last 10% of the lifting phase, as the hip came towards full extension in each of the three lifts. At this time, the hip thrust elicited a greater hip extensor moment than the deadlift, which in turn elicited a greater moment than the back squat.

Previous studies have compared EMG activity between the hip thrust and back squat (Contreras et al., 2015), and between the hip thrust and deadlift (Andersen et al., 2018), but have not compared joint kinetics, and not in all three exercises in the same study, as has been done here. Contreras et al. (2015) found that the barbell hip thrust activated the gluteus maximus and biceps femoris to a greater degree than the back squat when using estimated 10RM loads. Andersen et al. (2018) found that the barbell hip thrust activated the gluteus maximus to a greater degree than the deadlift, but that the deadlift activated the biceps femoris to a greater degree than the hip thrust in a 1RM lift.

From a practical perspective, it is clear that the hip thrust, deadlift and back squat all have potential to increase hip extensor strength. However, the results of this study, taken with those of Contreras et al. (2015) and Andersen et al. (2018) show that there are local differences between the exercises throughout the lifting phase. These local differences, might affect the

joint angles at which strength is most effectively developed, and should be considered within exercise selection to ensure adaptations in the hip extensor muscles are relevant to the athlete and sport in question. Additionally, the data from this study do provide some support to the finding of Contreras et al. (2017) that the hip thrust is more effective for sprint acceleration training than the front squat, since it does load the hip extensors to a greater extent near full extension than the back squat.
Limitations of the current study included that the 1RM values for the participants' hip thrusts were only slightly larger than for the deadlift, suggesting they perhaps weren't quite as well trained in the hip trust. Nevertheless, the 1RM values for both lifts in this study were slightly higher than those in the recent study by Andersen et al., (2018). Future research in this area should seek to provide a comprehensive description of the joint kinetics across all active joints in the lifts, in order to quantify the relative contribution of the hip extensor muscles. Furthermore, a comparison across a range of external loads will be valuable in understanding the differing characteristics of the three exercises. A more comprehensive biomechanical analysis will afford the practitioner additional information, to facilitate objective decisions within exercise selection to target specific adaptations.

CONCLUSION: To the authors' knowledge, this is the first study to empirically quantify hip joint kinetics in the barbell hip thrust, deadlift and back squat. The deadlift elicited the greatest hip extensor moment when the hip joint was in a more flexed position, whereas the hip extensor moment was greatest in the hip thrust exercise when the hip joint was approaching full extension. Careful consideration of the desired adaptation is recommended when selecting exercises to strengthen the hip extensor muscles.

REFERENCES:

Andersen, V., Fimland, M.S., Mo, D-A., Iversen, V.M., Vederhus, T., Rockland Hellebo, L.R., Nordaune, K.I. & Saeterbakken, A.H. (2018). Electromyographic Comparison of Barbell Deadlift, Hex Bar Deadlift, and Hip Thrust Exercises: A Cross-Over Study. *Journal of Strength and Conditioning Research,* 32(3), 587-593.

Bezodis, I., Brazil, A., Palmer, J. & Needham, L. (2017). Hip Joint Kinetics during the Barbell Hip Thrust. *ISBS Proceedings Archive*: 35(1), Article 184. https://commons.nmu.edu/isbs/vol35/iss1/184

Contreras, B., Cronin, J. & Schoenfeld, B. (2011). Barbell Hip Thrust. *Strength & Conditioning Journal,* 33(5), 58-61.

Contreras, B., Vigotsky, A.D., Schoenfeld, B.J., Beardsley, C. & Cronin, J. (2015). A Comparison of Gluteus Maximus, Biceps Femoris, and Vastus Lateralis Electromyographic Activity in the Back Squat and Barbell Hip Thrust Exercises. *Journal of Applied Biomechanics*, 31(6), 452-458.

Contreras, B., Vigotsky, A.D., Schoenfeld, B.J., Beardsley, C., McMaster, D.T., Reyneke, J. & Cronin, J. (2017). Effects of a six-week hip thrust versus front squat resistance training program on performance in adolescent males: A randomized-controlled trial. *Journal of Strength and Conditioning Research,* 31(4), 999-1008.

Legg, H.S., Glaister, M., Cleather, D.J. & Goodwin, J.E. (2017). The effect of weightlifting shoes on the kinetics and kinematics of the back squat. *Journal of Sports Sciences*, 35(5), 508-515.

Nichols, T. E., & Holmes, A. P. (2002). Nonparametric permutation tests for functional neuroimaging: a primer with examples. *Human Brain Mapping*, *15*(1), 1-25.

Selbie, S.W., Hamill, J. & Kepple, T.M. (2014). Three-dimensional kinetics. In: Robertson, G.E., Caldwell, G.E., Hamill, J., Kamen, G. & Whittlesey, S.N. (Eds) *Research Methods in Biomechanics (2nd Edition)*. Champaign, IL: Human Kinetics; 151-176.

Southwell, D.J., Petersen, S.A., Beach, T.A.C. & Graham, R.B. (2016). The effects of squatting footwear on three-dimensional lower limb and spine kinetics. *Journal of Electromyography and Kinesiology*, 31, 111-118.

Swinton, P.A., Stewart, A., Agouris, I., Keogh, J.W.L. & Lloyd, R. (2011). A Biomechanical Analysis of Straight and Hexagonal Barbell Deadlifts Using Submaximal Loads. *Journal of Strength and Conditioning Research*, 25(7), 2000-2009.

Acknowledgement: The authors thank Mike Long and Jac Palmer for their data collection assistance.